Test Evolution: RADARSAT-1 to RADARSAT-2

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Abstract— **Test methodology for large spacecraft like RADARSAT-1 and RADARSAT-2 has been modified over the last decade resulting in changes to test environments. These changes in the required test environment have necessitated improvements in the test configuration modelling, instrumentation, and data acquisition systems. This paper will identify the significant changes and how the RADARSAT-2 Assembly Integration and Test program has implemented these improvements.**

Keywords- RADARSAT-2; test; satellite

I. INTRODUCTION

The RADARSAT-2 spacecraft design has evolved from RADARSAT-1 with improvements in image resolution, type of beams, operational flexibility and mission life. In order to verify the performance capability of this spacecraft the Assembly Integration and Test process has also evolved to allow earlier retirement of risk elements, more fidelity in test results and establishes a higher degree of confidence in the spacecraft operation prior to launch. This paper describes the areas where significant changes in methodology or test technology have been used to achieve these improvements.

II. SPACECRAFT ASSEMBLY INTEGRATION AND TEST PROGRAM

The RADARSAT-2 spacecraft AIT program is largely based on the RADARSAT-1 AIT sequence due to the similar design of the spacecraft orbital configuration, the launcher requirements and the use of the same integration and test facilities at the CSA's David Florida Laboratory in Ottawa Canada. The AIT campaign is fully described in Reference [1].

In orbit the –Y face of the spacecraft is normally sun facing and the appendages are deployed in a way that is easily modeled thermally. As a result the appendages are not required during the SC Thermal Vacuum testing. Given the complexity and duration of integrating the appendages (particularly the SAR Antenna) it was decided, as in the case of RADARSAT-1, that the normal AIT sequence would be inverted (i.e. TVAC before Dynamic Testing) so that the SAR Antenna integration would only be required once.

Due to the delivery timing of the Bus and Payload it was decided to perform a TVAC test of the spacecraft with a thermally representative +Y Payload electronics carrying panel

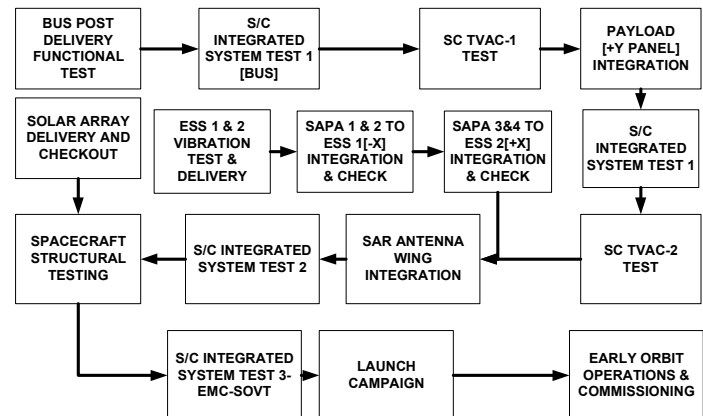to allow Thermal Model correlation since no thermal testing was done at Bus level.

Figure 1. RADARSAT-2 SC AIT Sequence

III. APPROACH TO INTEGRATED SYSTEM TESTING

The RADARSAT-1 AIT program used an industry standard approach at that time in the development of Electrical Ground Support Equipment [EGSE] and associated software to conduct the integrated system testing of the spacecraft. The Bus supplier provided a suite of test equipment, test scripts and software that enabled operators to command the spacecraft and receive telemetry for processing.

This infrastructure was applied to the Payload supplier as the user interface during the Payload integration phase to facilitate integration of the Payload test operations with the Bus test methods at spacecraft level. The Bus EGSE was further expanded to form part of the Mission Control System for in-orbit operations. Application of the Bus EGSE and operating system to the Payload and the subsequent expansion of its capability for orbital operations proved to be complex.

In the initial planning stages of the RADARSAT-2 AIT program it became apparent that the approach taken by the North American Payload provider did not yield an integrated Payload suite of test equipment that could be easily integrated with the European style test equipment and operating system of the Bus supplier. Furthermore the development of the Mission Level Spacecraft Control System [SCS] was on a separate path that would lead to a significant level of duplication between the

		Form Approved *OMB No. 0704-0188*

Report Documentation Page

1. REPORT DATE **25 JUL 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Test Evolution: RADARSAT-1 to RADARSAT-2**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **MacDonald, Dettwiler and Associates Richmond, B.C., Canada**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES **See also ADM001850, 2005 IEEE International Geoscience and Remote Sensing Symposium Proceedings (25th) (IGARSS 2005) Held in Seoul, Korea on 25-29 July 2005. , The original document contains color images.**

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**4**	

spacecraft test and mission operations test programs if the RADARSAT-1 approach were adopted.

The decision was made to apply the Mission Operations SCS equipment and operating system to the Payload aspects of spacecraft level integration. This approach allowed both Spacecraft AIT and Operations teams to become familiar with the in-orbit operating system from an early stage of development. It also allowed expertise from both groups to be implemented into the test procedures and the operating procedures.

During Integrated System Testing both the Bus EGSE and the SCS are linked to the spacecraft. To perform normal housekeeping and Bus specific tests, the Bus EGSE is used while the SCS is maintained in a "Listen-in" mode whereby the operators can obtain telemetry from both systems. When Payload tests are conducted the Bus EGSE places the spacecraft in the desired "initial" mode and then control is given to the SCS operators to run through the Spacecraft test procedures exercising Payload functions.

The benefits of this approach have been significant. The control and maintenance of the Spacecraft Data Base has been centralized. The generation of SC AIT Test procedures and Mission Operations procedures has a high degree of commonality thereby reducing duplication. The development of SC AIT procedures has been decoupled from Payload level test activities that were less applicable to SC level Integrated System Tests. Finally the AIT and Operations teams have succeeded in developing Operations Scenario Style tests that fully test the concurrent functionality of the SC subsystems at performance limits in orbital sequences. These sequences simulate a range of imaging and autonomous mode transition functions that demonstrate the spacecraft meets the mission requirements.

IV. IMPROVEMENTS TO SPACECRAFT THERMAL VACUUM TESTING AND MODEL CORRELATION

A. Infra Red Illumination Technique

The RADARSAT-1 spacecraft thermal vacuum testing was conducted at the CSA's DFL laboratory in Ottawa using their 7 m diameter by 10m deep top loading TVAC chamber. The spacecraft temperature is controlled by means of a LN_2 shroud to provide a cold-wall and heater plates or Infra Red lamps to heat areas of the spacecraft. This same chamber has been used for the RADARSAT-2 spacecraft TVAC testing, however, several of the data acquisition systems and chamber control systems have been upgraded since then.

Controlling the heat input to the spacecraft is achieved by producing an IR lamp "cage" around the spacecraft. A software-modeling tool called IRRIDESCENT specified the number of lamps, intensity and location for each lamp. This newly developed tool is a significant improvement over that which was used during all the previous spacecraft programs including RADARSAT-1. The tool uses inputs of radiated zone size, lamp characteristics, and spacecraft surface properties to accurately predict the geometry of the lamps

required to produce the required environment. The lamp configuration is also defined by the use of highly reflective "baffles" which set up parallel reflection zones that even out the IR lamp radiation incident on the spacecraft surface. This method was used on RADARSAT-1 with acceptable results; however, the improved IR lamp definition tool combined with a redesigned IR flux measurement instrument has provided exceptional correlation between the predicted test environment and the measured data. The RADARSAT-2 Spacecraft configuration for SC TVAC-1 is shown in Figure 2.

B. Absorbed Infra Red [IR] Flux Measurement

In order to perform Thermal Balance testing of the spacecraft it is necessary to know with high accuracy the actual IR input flux to each face of the spacecraft during testing. The instruments that measure this flux are generically termed Radiometers.

The radiometers that were used for the RADARSAT-1 I/R testing at DFL were developed between industry and CSA/DFL in the mid 1980's. Their operation depended on measuring the temperature of the sensing disc, and of the body that surrounds the edge and back of that disc. The thermal balance equation is complex because of the many conductive and radiative paths for heat flow in and out. This makes the initial calibration complex and challenges the data processing system. Those Radiometers were difficult to make and calibrate.

When the RADARSAT-2 program began developing its SC TVAC test configuration there was no mechanism for re-calibration of the existing radiometers despite them being the only device available to measure the essential IR flux input during the test.
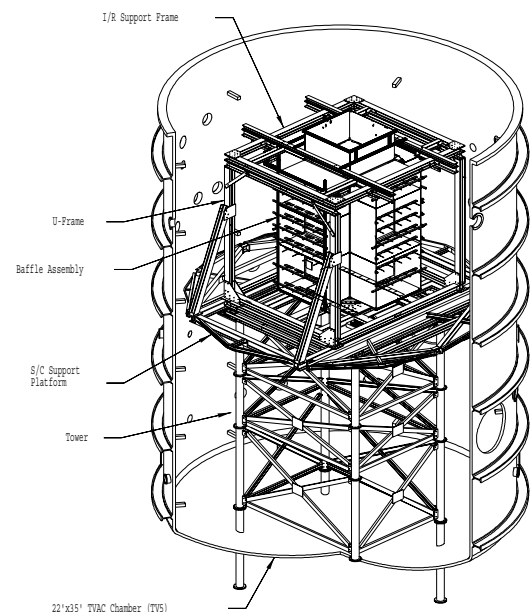

Figure 2. RADARSAT-2 SCTVAC-1 Configuration

In response to this concern, MDA devised a new radiometer named a "Guarded, Isothermal, Infra-Red, Opto-calorimeter" [GIIRO] that was much simpler to manufacture and removed the complex calibration process from the device.

The complexity was transferred from the measurement device inside the TVAC chamber to the associated conditioning electronics that is now sufficiently advanced to quickly process the data from the device. In addition the electronics remains available for use with devices with different surface finishes.

These devices have now been successfully used on the RADARSAT-2 SCTVAC-1 test where IR fluxes were accurately measured in the difficult range below 50 W/m^2 (simulating earth albedo).

C. Thermal Model Correlation

The substantial improvement of Thermal Mathematical modeling techniques since the RADARSAT-1 thermal testing has allowed thermal design engineers to generate highly refined spacecraft thermal models. The Bus supplier was also assigned the responsibility for the overall spacecraft thermal design and therefore central to the specification of the RADARSAT-2 thermal vacuum test requirements.

Due to the fidelity of the software predictions it was recognized that the higher the accuracy of the test data; the higher the probability that there would be good correlation between the test results and the test predictions. These requirements for higher accuracy were established in 3 areas; temperature data; IR flux data over a large range of illumination levels; and measured Spacecraft surface properties data.

Temperature data was made available to the thermal engineers from the flight thermistor telemetry through the SC EGSE linked through the DFL's Control and Data Acquisition System (CDACS) to the Thermal Test Monitor stations to an accuracy of ± 3 C. The test thermocouples, which monitored both the SC and the GSE inside the chamber, were accurate to within ± 0.5 C.

The Absorbed IR Flux measurements were characterized to an accuracy of better than ± 8% at IR illumination levels with IR lamp powers as low as 5 watts. With this exceptional data set the Bus supplier has reported a Thermal Balance correlation between the Thermal Math Model and the SCTVAC-1 test data of > 95% for test cases.

The characteristics of the Spacecraft surface properties (α/ε) were measured using the AZ Technology's TESA 2000 portable measurement instrument.

V. Appendage Deployment and Alignment

The RADARSAT-1 program incorporated specially developed deployment systems for both the solar arrays and SAR Antennas. Since all of these systems required full Qualification an extensive suite of deployment tests were specified at all levels of assembly. In particular these included full deployments of each SAR Antenna wing and partial deployments of the full Solar Array Wing under TVAC conditions. As a result of those tests some design issues were identified and resolved prior to flight.

The RADARSAT-2 program was able to take a different approach resulting in a high level of confidence in the deployment systems through unit level testing without the need for extensive testing at the Wing assembly level.

A. Solar Array Wing Testing

The Bus supplier selected a Solar Array Wing from a vendor with a qualified design that required limited adjustments for integration into the Bus design. As a result the release and deployment mechanisms were all acceptance tested at unit level. The only remaining verification tests at spacecraft level are ambient deployments pre-post SC Structural testing.

B. SAR Antenna Tie-Down [ATD] Testing

The design for the SAR Antenna Wing tie-downs was assigned to the Bus supplier, as it was a significant load path on the spacecraft. The ATD design was subjected to full Qualification testing and release was verified after being subjected to thermal cycling. Each ATD was subjected to full environmental acceptance testing as a unit and so TVAC testing of release of the SAR Antenna Wings at Wing or SC level was not required. The remaining ATD verification is ambient environment release post SAR Antenna Panel integration.

C. Extendible Support Structure[ESS] Testing

The RADARSAT-2 ESS has a similar geometry to the ESS used on the RADARSAT-1 program due to the configuration of the SAR Antenna Panels. In order to gain confidence in the mechanism, the most complex of the joints was subjected to Qualification testing and demonstrated performance during TVAC cycling. The Deployment Motor Assembly was also qualified and each unit underwent TVAC Acceptance testing. At the ESS Subsystem level each deployable truss assembly received several deployment cycles in a thermal chamber at operating temperature extremes. Figure 3 shows ambient deployment testing of the ESS with mass representative dummy SAR Antenna Panels.
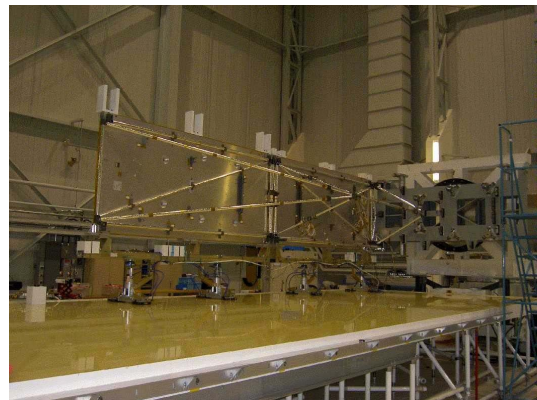

Figure 3. Extendible Support Structure Deployment Testing (photo by permission of Able Engineering)

D. SAR Antenna Wing Testing

In the RADARSAT-1 program the three elements making up the SAR Antenna Wing (SAR Antenna Panels, ESS, and ATD's) were acceptance tested at the subsystem level as an assembled Wing. Due to the unit testing approach taken on RADARSAT-2, the release and deployment elements of the SAR Antenna Wing were verified at a lower level of assembly and therefore the complexity of performing this test at the wing level was not necessary.

The new design of the RADARSAT-2 SAR Antenna resulted in each of the 4 SAR Antenna Panels having a mass approximately twice the mass of the RADARSAT-1 panels. This resulted in a requirement to upgrade the air-bearing offload deployment system to be much more robust. The strength of the deployment table surface was increased to minimize deflections as the air-bearing system supported the SAR Antenna Wings during deployment. Each of the air-bearing supports was equipped with load cells to enable the load distribution to be monitored during deployment for safety and trend analysis.

Alignment measurement of the RADARSAT-2 SAR Antenna will benefit from both the speed and accuracy of the Laser Tracker system. For RADARSAT-1 a computer aided theodolite system was used that required significantly more set-up and measurement time to achieve the required results. The Laser Tracker data will be used in conjunction with Computer Aided Design SW models to allow deployment/stowage geometry to be checked prior to final alignment adjustment.

VI.   CONCLUSION

The RADARSAT-1 AIT program served as foundation for the development of new AIT techniques to respond to the evolving requirements of the RADARSAT-2 program. In most cases the RADARSAT-2 AIT program has been able to reduce the number of test activities at Spacecraft level and their complexity without reducing confidence in the spacecraft design and construction.

VII.   REFERECES

[1]   Z. Ali, G. Kroupnik, G. Matharu, J. Graham, I. Barnard, P. Fox and G. Raimondo, "RADARSAT-2 space segment design and its enhanced capabilities with respect to RADARSAT-1", Canadian Journal of Remote Sensing Volume 30 No. 3, June 2004, pp 235-245.